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The International System of Units (SI) and Medicine

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A major international movement is in progress to extend metrication using the International System of Units. Significantly involved is the field of medicine. Extensive changes adopted abroad now appear in foreign medical literature, and physicians in the United States commonly are unprepared to interpret medical information from abroad because the data are reported in unfamiliar terms. The system has broad immediate and future implications to American physicians.

THE BRITISH IMPERIAL SYSTEM OF WEIGHTS, which is now used in the United States, originated from a variety of ancient cultures. The awkward base number 12 is Roman in origin. The yard was established by royal decree as the distance from the tip of the nose to the end of the thumb of King Henry I. The inch was based on the size of three grains of barley. Other equally illogically derived units eventually evolved into the irrational English system.[1]

The metric system, by contrast, with its base 10 or decimal system derived its units of mass and volume from its units of length, thus correlating its basic units. The need for further refinement of metrics into a single worldwide and interdisciplinary system of measurements led to the development of the International System of Units (le Système International d'Unités), with the international abbreviation SI. This has been referred to as "the modern metric system" and is said to complete the process of metrication.[2]

The Metric Conversion Act of 1975 passed by the United States Congress states, "It is therefore declared that the policy of the United States shall be to coordinate and plan the increasing use of the metric system. . . ."[3] This is intended to be voluntary with no specific deadline mandated. The term metric system as used in the act refers to SI.

The International System of Units

SI is a system of "base units" and "derived units" and their interrelationships. Seven base units and two supplementary units have been adopted (Table 1). Each unit can be defined in specific terms. The mole, for example, is the amount of substance that contains as many elementary entities as there are atoms in 0.012 kilograms of carbon 12. Base units are multiplied and divided to form derived units (Table 2). The newton (the SI unit for force), for example, is derived from three base units according to the expression $m \cdot kg \cdot s^{-2}$. Derivation promotes calcu-

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lation and understanding. Table 3 lists the prefixes denoting multiples of SI units.

Although both mass concentration (grams per liter) and substance concentration (moles per liter) are recognized in the SI system, there are certain purported advantages to recording data in substance concentration. Certain biological relations between blood constituents may be made clear when measurement is on the basis of their relative number (moles). Such relations may be masked by usage of mass concentration but may be better visualized in molar terms. Consider, for example, an unconjugated bilirubin concentration of 0.4 mg per dl and a serum albumin of 4.0 grams per dl. The concentration of bilirubin might appear to be 1/10,000 of that of albumin. In molar terms, however, there is only a 100-fold difference. The same concentrations are 6.8 and 620 μmol per liter, respectively. A serum bilirubin concentration of 20 mg per dl, which is a level of clinical importance in neonatology, is 340 μmol per liter, or more than half the concentration of albumin in this example.[4]

A more familiar example concerns the reporting of electrolytes. Sodium, potassium, chloride and carbon dioxide are reported in milliequivalents. The divalent ions, calcium and magnesium, are often expressed as mg per dl. It is difficult to understand ionic balance when diverse terminology is used. SI would create consistency.

Advantages

The present method by which values are reported by medical laboratories is disorganized. Physicians are accustomed to a nonsystem of units that developed over many years with little planning or logic. As a result, it is necessary to memorize normal limits as well as the particular unit involved for an enormous number of indi-

TABLE 1.—*SI Base Units*

Quantity	*Name*	*Symbol*
Length	Meter (metre)*	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Thermodynamic temperature†	Kelvin	K
Amount of substance	Mole	mol
Luminous intensity	Candela	cd
Supplementary units		
Plane angle	Radian	rad
Solid angle	Steradian	sr

*Both spellings acceptable.

†The Kelvin (the unit for thermodynamic temperature), not the degree Celsius, is in fact the SI unit for temperature. Their scale origins differ, but the degree Celsius equals the Kelvin in magnitude; thus, a rise in body temperature of 1.0 K is equivalent to a rise of 1.0°C, 0°C is defined as 273.15 K, therefore 98.6°F = 37°C = 310.15 K. The Celsius temperature scale (formerly called centigrade) is used for most medical and commercial purposes.

TABLE 3.—*SI Prefixes**

	Prefix			*Prefix*	
Factor	*Name*	*Symbol*	*Factor*	*Name*	*Symbol*
10^{18}	exa-	E	10^{-18}	atto-	a
10^{15}	peta-	P	10^{-15}	femto-	f
10^{12}	tera-	T	10^{-12}	pico-	p
10^{9}	giga-	G	10^{-9}	nano-	n
10^{6}	mega-	M	10^{-6}	micro-	μ
10^{3}	kilo-	k	10^{-3}	milli-	m
10^{2}	hecto-	h	10^{-2}	centi-	c
10^{1}	deca-	da	10^{-1}	deci-	d

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TABLE 2.—*Some SI Derived Units**

Quantity	*Name*	*Symbol*
Area	Square meter	m^2
Volume	Cubic meter	m^3
Velocity	Meter per second	m/s
Wave number	1 per meter	m^{-1}
Density, mass density	Kilogram per cubic meter	kg/m^3
Concentration (amount of substance)	Mole per cubic meter	mol/m^3
Activity (radioactive)	1 per second	s^{-1}
Specific volume	Cubic meter per kilogram	m^3/kg
Luminance	Candela per square meter	cd/m^2
Frequency	Hertz	$Hz = s^{-1}$
Force	Newton	$N = m \cdot kg \cdot s^{-2}$
Pressure	Pascal	$Pa = N/m^2 = m^{-1} \cdot kg \cdot s^{-2}$
Energy, quantity of heat, work	Joule	$J = N \cdot m = m^2 \cdot kg \cdot s^{-2}$
Power	Watt	$W = J/s = m^2 \cdot kg \cdot s^{-3}$
Electric potential, potential difference, electromotive force	Volt	$V = W/A = m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
Electric resistance	Ohm	$\Omega = V/A = m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$

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vidual laboratory determinations, or take time to review this information on each occasion.

To further obfuscate the situation, normal limits vary from laboratory to laboratory. No master plan exists. SI, to a great extent, introduces uniformity to units: a few rules replace memorization. Not only is an attempt being made to standardize unitage, but ideas are coming forth to standardize normal values as well.[5]

A unifying proposal, then, is to express all concentrations as units per liter. (The multipliers are to be used in the numerator rather than the denominator.) Also proposed, when molecular weights are known, is the use of molecular units. Thus, most concentrations would be moles per liter or a multiple (see Table 4). The trade-off is as follows: although unitage would attain simplification and consistency, the change requires new numbers for almost every common chemical determination except electrolytes. Phased adoption has been suggested for the United States.[6] It has been recommended that conversion to molecular units not be automatic, but analytes be considered on an individual basis.[7]

One goal of metric conversion is that scientists of all varieties and nationalities might eventually communicate in the same units of measure. There would be an increase in ease and precision of scientific communication and avoidance of misunderstanding and error by international agreement. SI has the advantage of being logical, systematic, international and interdisciplinary.

Uncertainties and Problems

A potential disadvantage during introduction is danger to the patient by possible error engendered through unfamiliarity. For example, possible high and low serum values for digoxin are 5.0 mg per dl and 0.5 mg per dl, respectively. In SI terms, the second value becomes 5.0 mg per liter. Misreading this value as 5.0 mg per dl could lead to therapeutic error.[6] Two Canadian hospitals, however, reported conversion to SI units without harm to patients.[8] It has been suggested that medical publications use dual reporting for a period of time, using both SI and traditional units as clinicians learn the system.

Two of the SI-derived units relating to medicine are at present unknown to most clinicians. It is recommended that the joule replace the calorie in

TABLE 4.—*Some Factors for Converting Clinical Laboratory Concentration Data from Conventional to SI Molar Units**

Component	*Conventional Units*	× *Factor*	*= in SI Units*
Albumin	grams/dl	10.0	grams/liter
Bicarbonate	mM	1.0	mmol/liter
Bilirubin	mg/dl	17.1	μmol/liter
Calcium	mg/dl	0.25	mmol/liter
	mEq/liter	0.5	
Chloride	mEq/liter	1.0	mmol/liter
Cholesterol	mg/dl	0.026	mmol/liter
Creatinine	mg/dl	88.4	μmol/liter
Globulins	grams/dl	10.0	grams/liter
Glucose	mg/dl	0.055	mmol/liter
Iron	μg/dl	0.179	μmol/liter
Phosphorus	mg/dl	0.323	mmol/liter
Potassium	mEq/liter	1.0	mmol/liter
Protein, total	grams/dl	10.0	grams/liter
Sodium	mEq/liter	1.0	mmol/liter
Thyroxine	μg/dl	13.0	nmol/liter
Triglyceride	mg/dl	0.011	mmol/liter
Urea nitrogen	mg/dl	0.357	mmol/liter
Uric acid	mg/dl	0.059	mmol/liter
Complete blood count (CBC):			
Hematocrit	%	0.01	
Hemoglobin	grams/dl	10.0	grams/liter
Erythrocyte count	$10^6/\mu l$	10^6	10^{12}/liter
Leukocyte count	$10^3/\mu l$	10^6	10^9/liter
Erythrocyte indices:			
Mean corpuscular volume	cubic microns	1.0	fl
Mean corpuscular hemoglobin	pg	1.0	pg

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TABLE 5.—*Units and Conversion Factors for Quantities Used in the Clinical Laboratory**

Quantity	Conventional Unit Name	Symbol	× Factor	= in SI Units Name	Symbol
Energy, work	Calorie	cal	4.187	Joule	J
Frequency	Per minute	min^{-1}	0.0167	Hertz (per second)	$Hz(s^{-1})$
Power	Kilocalorie per minute	kcal/min	69.8	Watt	W
	Horse power (metric)	HP	0.736	Kilowatt	kW
Radiation units:					
Absorbed dose	Rad	rd	0.01	Gray	Gy
Equivalent absorbed dose	Rem	rem	0.01	Joule per kilogram	J/kg
Radioactivity	Curie	Ci	37.0	Giga becquerel	GBq
	Roentgen	R	0.258	Millicoulomb per kilogram	mC/kg
Pressure	Millimeter of mercury	mm Hg	0.133	Kilopascal	kPa

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nutrition and dietetics. One calorie equals 4.184 J; therefore, a 1,000-calorie diet equals a 4.18 kilojoule diet.

Equally unfamiliar is the pascal, the SI unit of pressure. Blood pressures are now recorded in a metric unit, the millimeter of mercury (or torr). The pascal ($kg \bullet m^{-1} \bullet s^{-2}$ or the newton per square meter) is proposed to replace all other pressure units. Although too small for conventional clinical use, the kilopascal (10^3 pascal) has an appropriate magnitude. A kPa is equal to 7.5006 mm of mercury. A blood pressure of 130/80 would, therefore, be approximately 17/11 kPa. Retention of mm of mercury in the United States for the present has been recommended.[7]

An especially perplexing problem is the measurement of enzymatic activity. The previously introduced international unit is defined as the amount of enzyme that will catalyze the transformation of 1 micromole of substrate per minute under standard conditions. Acceptance of this unit has been slow, and many conventional units are still used. To conform with SI, a new base unit for enzymatic activity named the katal (one mole per second) has recently been proposed.

There is in use, in measuring enzymes, a wide variety of methods as well as conditions, such as pH and temperature. Attempts are being made at the international level to standardize assay conditions. Commonly, the mass and purity of many proteins are unknown, thus compounding the problem.

A recent survey showed extensive worldwide acceptance of SI units in medicine, especially the molar concentrations. However, in most countries the katal has not been adopted, protein is usually measured in grams per liter, mm of mercury is preferred to kPa and pH is preferred to nmol per liter as a measure of hydrogen ion concentration. Most countries reported the change to new units caused little trouble.[9]

Current Efforts

The American National Metric Council (ANMC) assumed the herculean task of gaining consensus in metrication by involving multiple scientific disciplines, consumers and industry simultaneously. The Medical and Health Coordinating Group of the ANMC is being organized with William R. Barclay, MD, as chairman. A wide variety of medical specialties and health organizations are being invited to participate in developing consensus regarding metrication in medicine.

Use of SI

Excellent and extensive reviews of the details of SI exist, including conversion tables and guidelines for usage.[2,10,11] Tables 4 and 5 summarize selected conversion data for items of common interest in medicine.

REFERENCES

1. Brief History of Measurement Systems with a Chart of the Modernized Metric System. National Bureau of Standards, Washington DC, Aug 1976

2. Lehmann HP: Metrication of clinical laboratory data in SI units. Am J Clin Pathol 65:2-18, 1976

3. Metric Conversion Act of 1975, Public Law 94-168. 89 Stat, 1007

4. Young DS: Standardized reporting of laboratory data—The desirability of using SI units. N Engl J Med 290:368-373, 1974

5. Langdon DE: SI units and enzyme levels. JAMA 241:1229, 1979

6. Powsner ER: SI units and the clinical laboratory. Arch Pathol Lab Med 103:491-494, 1979

7. Duel WC: Minutes of the March 23, 1980, meeting of the SI and Metrication Advisory Panel to the American Medical Association Council on Scientific Affairs, Atlanta, Georgia

8. Karnauchow PN, Suvanto L: Experience with SI units in biochemistry. Can Med Assoc J 114:533-536, 1976

9. Ritchie AC: SI worldwide. CAP Newsletter 22:5-6, 1980

10. Lippert H, Lehmann HP: SI Units in Medicine: An Introduction to the International System of Units with Conversion Tables and Normal Ranges. Urban & Schwarzenberg, Baltimore, 1978

11. The SI for the Health Professions. Geneva, World Health Organization, 1977